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Original Article

Static Analysis of the Most Weakness Part of Temporale Bone Using Finite Element Method and Its Clinical Importance

Sonlu Elemanlar Yöntemi Kullanılarak Temporal Kemiğin Zayıf Noktalarının Statik Analizi ve Klinik Uygulaması

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Abstract: Human body have a complex structure. So, examine this structure require advanced level of engineering tools. In this study, temporale bones obtained from six different person were examined under the pressure of 5000 Pa. Stresses occurred on these bones under the applied pressure were determined using ANSYS Workbench finite element software. Total deformations were seen always on squamous part of the bones. This situation can be important for the clinical relevance of temporal trauma.
Keywords: Biomechanics, Finite element method, Temporale bone

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Öz: İnsan vücudu karmaşık bir yapıya sahiptir. Bu nedenle bu yapıyı incelemek için ileri düzeyde mühendislik araçlarına gereksinim vardır. Bu çalışmada, 5000 Pa basınçta altı farklı kişiden elde edilen temporal kemikler incelenmiştir. Bu basınç altında kemikler üzerinde meydana gelen gerilmeler, ANSYS Workbench yazılımı ile sonlu elemanlar yöntemi kullanılarak belirlenmiştir. Toplam deformasyonlar genellikle kemiklerin skuamoz bölgelerinde görülmüştür. Bu durum, temporal travmaların klinik açıdan değerlendirilmesinde önemlidir.
Anahtar Kelimeler: Biyomekanik, Sonlu elemanlar yöntemi, Temporal kemik

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1. Introduction

In the past, developments in software technology have made it possible to rapidly generate 3D volumes from conventional 2D data (1-3). In recent days, complex structures of bones in human body have been investigated with the view of engineering, using some analysing methods. Custommade implants or prothesis are modelled by using Computer Aided Design (CAD)/Computer-Aided Manufacturing (CAM)/Computer-Aided Engineering (CAE) systems. After analysing these, preparations are fabricated properly.

Temporal bones are situated in the lateral sides and base of the skull. These are important because of the auditory and vestibular apparatus located in these bones. It is composed of squamous, petromastoid, tympanic and styloid parts. The squamous part helps enclosure of the brain. It is thin and partly translucent. Its outer temporal surface is smooth, slightly convex. The petromastoid part preserves precise orientation of the membranous labyrinth. Mastoid part is trabecular and variably pneumatized. The tympanic part forms the tympanic cavity and external acoustic meatus and supports the tympanic membrane, all concerned in sound transmission (4). Its superior border overlapes the inferior border of parietal bone. Its anterior border articulates with sphenoid bone. Occipital bone is located at posterior. Temporal bone has so important structure that it is essential to know how it will deal with a trauma. In this study, we aimed to analyse the reactions of temporal bones under a pressure, using finite element method.

2. Material and Methods

2.1. Materials

Six temporal bones taken from different humans obtained in Eskişehir Osmangazi University Faculty of Medicine Department of Anatomy were used. Some mechanical features of temporal bone were given in Table 1 (5).

Table 1.
Mechanical features of temporal bone

Material	Elasticity modulus (Pa)	Poisson's ratio	Density (kg/m^3)
Temporale bone	$1,71x10^{10}$	0.25	1600

2.2. Digitization of model

It is not possible to model the temporal bone, using traditional methods (Figure 1). In addition, bone was converted to numerical by reverse engineering because of different anatomy of body for each person. Reverse engineering is a very important branch of geometrically design and manufacture application area, and this technique has been widely recognized as being an important step in the product development cycle (6). In contrast to the traditional production sequence, reverse engineering typically starts with measuring an existing object, so that a solid model can be deduced in order to make use of the advantages of CAD/CAM/CAE technologies (7).

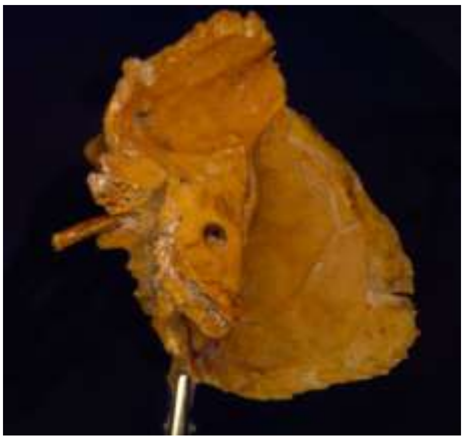

Figure 1. *Object (Temporal Bone) which will be scanned*

Point cloud of bone model were obtained via a kind of scanner (Nextengine scanner). Nextengine scanner has twin 3.0 megapixel cmos image sensors. Scanning process can be output as mesh file formats: STL,OBJ, VRML, XYZ, U3D and PLY files. This point cloud is converted to surface with CAD software. Scanning was performed by dropping the light to the surface of the bone with moving head, with the assistance of two digital camera. After scanning, point cloud was obtained. The point cloud of file (saved as *.asc document) is seen in Figure 2.

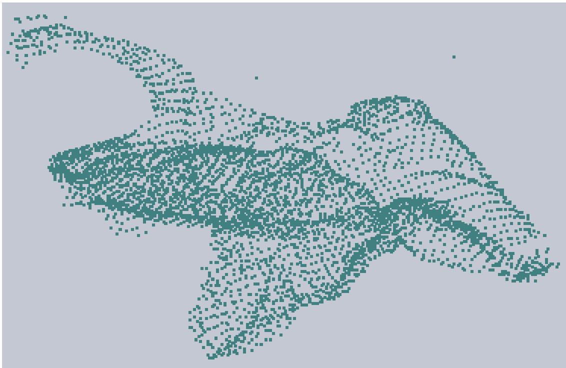

Figure 2. *Point cloud obtained from scanned object(Temporal Bone)*

2.3. Formation of CAD model of the object.

The object which had point cloud is opened in SolidWorks program as *.xyz format. Mesh is obtained from point cloud via Nextengine module of program. Traumatized or abraded parts in this mesh are determined. The mesh structure of object is seen in Figure 3.

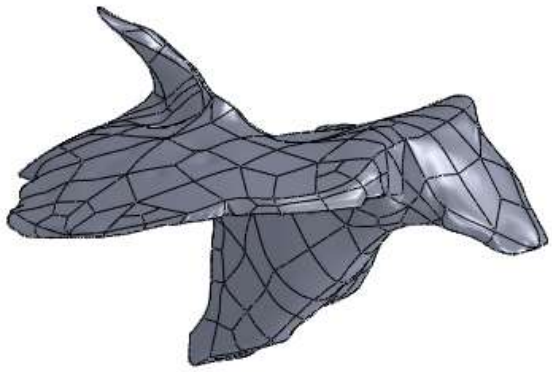

Figure 3. *CAD model obtained from Point cloud*

2.4. Finite element method(FEM)

Statistical analysis were made by FEM to determine the loads applied to temporal bone. ANSYS Workbench finite element software was prefered. In this study, temporal bones scanned by 3D NEXTENGINE scanner is transformed into surface model via ScanTo3D module in SolidWorks modelling software. These surface models were saved as IGES format and opened in AnsysWorkbench finite element software. But there were mistakes in making mesh in some surfaces. Defective surfaces were determined, corrected in SolidWorks and sent to AnsysWorkbench to repeat the analyse. Analyse type was choosen and after then, material values of temporal bones were entered. 10943 nodes and 5388 elements were obtained in temporal bone mesh. Mesh structure of bone is seen in Figure 4. The mesh type used in analysis was chosen as tetrahedrons.

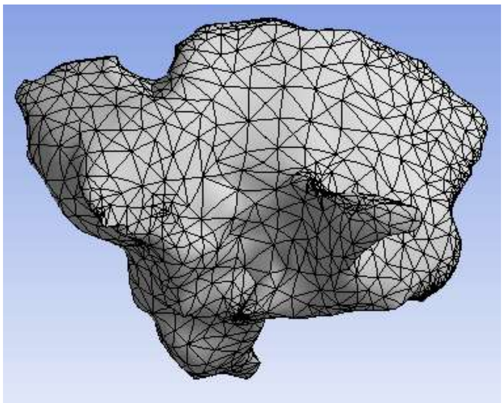

Figure 4. *Mesh structure of temporal bone*

Pressure, 5000 Pa was applied to temporal bone after the determination of boundary conditions. Boundary conditions applied to temporal bone and pressure value is seen in Figure 5. Maximum deformations on the bone surface were obtained after material features and boundary conditions were entered. The analyses were evaluated according to von Mises criteria. The von Mises criteria are generally used both ductile and brittle materials. The von Mises model is given more sensitive results than Tresca criteria.

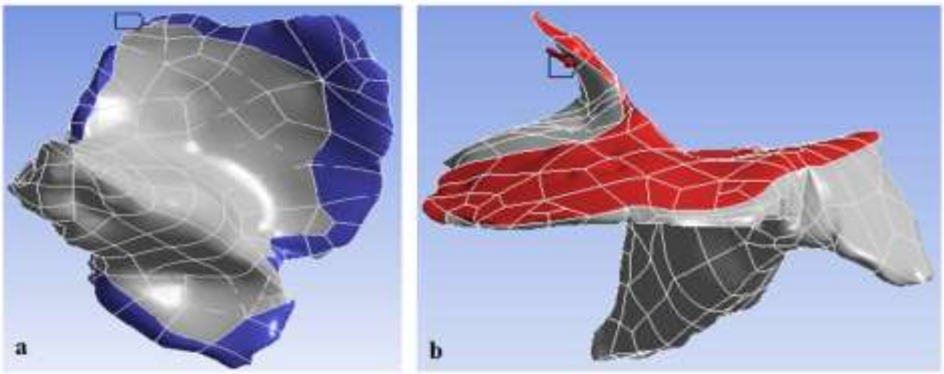

Figure 5. *a) Boundary conditions of the temporal bone. b) Pressure values applied on the temporal bone.*

3. Results

Total deformations were seen always on squamous part of the bones. Thickness of squamous part was less compared to the other parts. This property increases the probability of deformation in this part. Color distributions of deformation areas on bone surfaces are seen in Figure 6. Maximum deformations on bone surfaces are seen graphically in Figure 7.

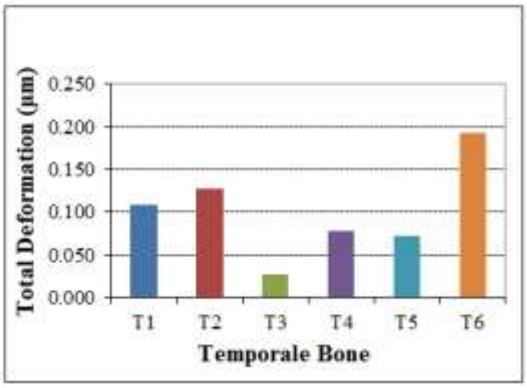

Figure 7. *Graphical view of maximum deformations on temporal bone surfaces*

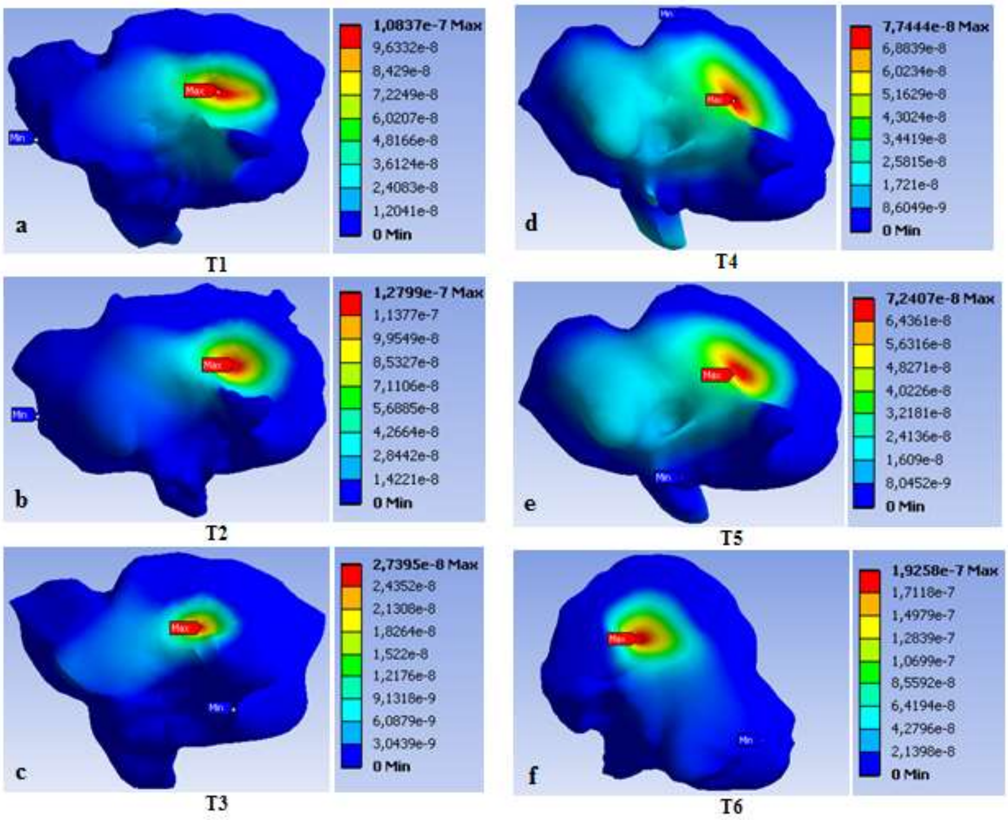

Figure 6. *Color distribution of the deformation areas on temporal bone surfaces. a) T1, b) T2, c) T3, d) T4, e) T5, f) T6*

It was observed that; approximately similar values are obtained in maximum deformations on bone surfaces. 3-numbered temporal bone had minimum deformation while 6-numbered bone had maximum.

The results for the comparison of total deformation with the physical measurements of temporal bones are given in Table 2. According to the statistical analysis, there is not any correlation between total deformation and volume and mass ($p>0.05$). These results originated from the special anatomical structure of temporal bone.

Table 2.
The comparison of total deformations with the physical measurements of temporal bones.

Temporal Bone	Volume (cm^3)	Mass (kg)	Total Deformation (µm)
T1	23,33	0,037	0,108
T2	40,84	0,065	0,128
T3	23,12	0,037	0,027
T4	30,83	0,049	0,077
T5	30,00	0,048	0,072
T6	32,07	0,051	0,193

4. Discussion

To make a computation model of defined function for the passage of soundwave through the ear, Gan and Sun re-constructed middle and inner ear as three-dimension (3D) and constituted the biomechanical features of temporal bone, using finite element analysing method (8). They obtained tissue sections from temporal bone, scanned these sections and after then digitized. They showed that this prepared model could be used in the future for the acustic analysis of ear.

Gan et al. examined whether it is possible to compose human temporal bone as 3D and make a combination of finite element analysing technologies (9). Finite element models in biological systems were used in ear biomechanics. They explained that it is impossible to compose a 3D model, using anatomical structures like ligaments and muscles, and instead of this, finite element can be used in 3D images which is composed by laser Doppler interferometer.

Lee et al. analysed the passage of soundwave through the air cells and human mastoid antrum by finite element methods (10). They examined middle and inner ear pressure distrubitions in different frequences. Completed finite element model for mastoid area can be used potentially. They showed that it is possible to obtain more information in the studies of middle ear biomechanics.

Beere et al. made a simulation for the dinamic behaviour of ear using finite element methods, to discover the function of human ear (11). They showed that it is possible to model the tympanic membran surface, malleus, incus and stapes as 3D.

The results for total deformation of temporal bone under this pressure values were obtained via AnsysWorkbench finite element software. Deformations which occured on bone surfaces with loading were shown as graphically. It was noticed that total deformations were seen always on squamous parts of bones. Squamous part was thinner compared to the other parts. That's why the probability of deformation in this part is higher than the other parts.

According to our knowledge, there is no any study in the literature which demonstrates that the highest deformation is at the squamosa part during a temporal trauma and using Finite Element Method (FEM).

5. Conclusion

Aspecting from a cranial trauma; the increaesed probability of the injury risk of squamosa part of the temporal bone is supported with this method. This situation can canalize the physician to the injury of the cerebrum near the inner part of the squamosa causing morbidity at the innervation areas. So that early diagnosis and treatment can be performed.

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